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A Sense Diary System for Intelligent Buildings

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Abstract: This paper presents a novel device called Sense Diary for intelligent buildings. To introduce the new device and its applied system, a brief review of sensor-based systems applied in buildings has been conducted, which is based on current literature and products. The aim of this review is to understand current research and development situation of sensor-based systems that have been developed for all kinds of buildings and their systems across the world, and to further identify specific research tasks for an UK government EPSRC funded project focusing on innovative solutions of building façade systems. For acquiring the knowledge of sensor-based systems for buildings, some target information sources have been subjectively chosen. According to the literature and products review, several key research tasks of a Sense Diary System have been identified and discussed. It is concluded that the proposed Sense Diary and its applied system have advantages in balancing well-being and energy efficiency in buildings.

Keywords: sensor, sensor-based system, buildings, intelligent buildings

Introduction

This paper aims to introduce a novel sensor-based subjective opinion feedback system called Sense Diary for intelligent buildings. The initiative of this research was led by Clements-Croome (2004) and is being deployed through an IDCOP (Innovation in Design, Construction & Operation of Buildings for People) research project <http://www.idcop.soton.ac.uk/>, which is funded by the Engineering and Physical Sciences Research Council (EPSRC) in UK.

The UK government EPSRC (2006) has been conducting a research programme called Sustainable Urban Environment (SUE) since 2001. The key drivers of the SUE programme are to improve the quality of life of UK citizens, to support the sustainable development of the UK economy and to meet the needs of users of EPSRC funded research in industry, commerce and the service sector. At current stage, the four areas with 12 research projects have been supported, including

- Urban and Built Environment (3 projects);
- Waste, Water and Land Management (4 projects);
- Transport (4 projects); and
- Metrics, Knowledge Management and Decision Making (2 projects).

Among these research projects, the IDCOP research project aims to develop innovative solutions with respect to the maintenance and refurbishment of existing buildings, specifically the aim of the IDCOP consortium is to find new ways to improve the performance of building envelopes over the

whole building lifecycle (IDCOP, 2005); and in order to achieve this target, the IDCOP consortia has two research themes, including

- To develop sustainable façade technologies and enhanced methods for building refurbishment, and
- To reduce the consumption of non-renewable resources in a way that is economically viable and socially acceptable.

With regard to the theme of the SUE programme, the sustainability is considered by the IDCOP consortia from people, process and product perspectives for multi-storey, multi-occupancy buildings of both the domestic and commercial sectors.

The research into a sensor-based system is linked to two IDCOP work packages or sub-projects, including embedded sensor systems and system personalisation. With regard to the themes and the specific requirements of the IDCOP research project, the research in to a Sense Diary System has been deployed to achieve the following research targets, including

- a prototype of embedded sensors system with focus on occupants' well-being,
- a Sense Diary and its applied system that can be used at either work or residential places to register various degrees of either satisfaction or dissatisfaction by occupants in regard to commonly design environmental factors of buildings,
- to evaluate physical conditions of buildings while a Sense Diary system is using,
- to describe the well-being state of the occupants while they are using Sense Diary, and
- to power real-time facilities management process.

According to this deployment, a 4-stage plan has been made, which comprises of

- *A review of sensor-based systems for buildings*,
- *A new prototype of Sense Diary*,
- *The development of the Sense Diary and its applied system*, and
- *An experimental case study*.

This paper focuses on a brief review of current status of sensor-based systems applied in buildings across the world, and a concise introduction of the proposed Sense Diary system to be used for intelligent control of buildings. The review is based on current literature and products relevant to sensors and their applications in buildings and their systems. The aim of this review is to understand current research and development situation of sensor-based systems that have been developed for all kinds of buildings and their systems across the world, so as to further identify specific research tasks for the IDCOP project with focuses on innovative solutions of building envelop systems. For acquiring knowledge of sensor-based systems for buildings, both academic and professional information sources have been subjectively chosen, including *ScienceDirect Navigator* and IEEE Computer Society Digital Library (*IEEE Xplore*) for literature review and *ThomasNet* and *Google* for products review. According to the literature and products review, several key research tasks of the Sense Diary system are identified and discussed. It is concluded that the proposed Sense Diary and it applied system has the advantage in balancing well-being and energy efficiency in buildings.

Methodology

Methods adopted in the review of literature and products and the development of the Sense Diary and its applied system comprise of information collection and study, and system analysis and design. Figure 1 illustrates a research framework for the review of literature and products and then the development of Sense Diary and its applied system. As illustrated in Figure 1, the research into a Sense Diary system for intelligent buildings has been divided into two stages in terms of related theoretical and methodological context, and the two research stages include

- The review stage. At this stage, comprehensive information will be collected from three sources, including academic information sources (such as the *ScienceDirect Navigator*, the IEEE Digital Library, i.e., the *IEEE Xplore* and the *Elsevier EI Compendex*), professional

information sources (such as the *ThomasNet*, the *Questex Media Group Sensors* and the *GlobalSpec Search Engine*), and general information sources (such as the *Google*). And

- The development stage. At this stage, system analysis and development method will be used to build up the Sense Diary system architecture and to program for a demo system.

With regard to each connection between a preceding stage and a following stage, which is based on a schedule for deploying each research task, a research and development strategy is to be set up; and it is the result of literature and products review and the guidance for developing the Sense Diary system.

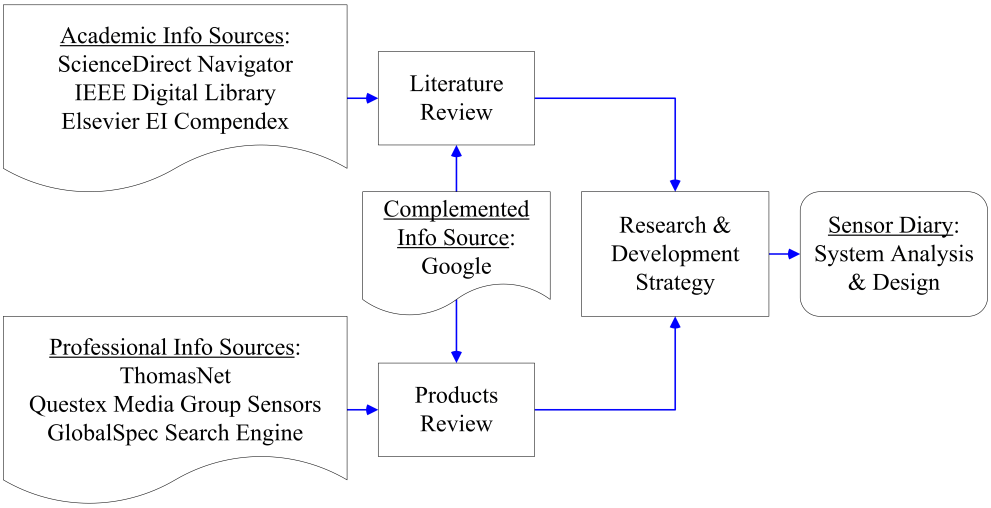

Figure 1: A framework of research processes.

There are plenty of information sources around the world; however, to select a source of information for literature and products review, two criteria are adopted, including whether it is the original source of relevant information and whether it is the authoritative source of relevant information. Based on these criteria, several online databases have been selected as academic information source, professional information source, or general information source (see Figure 1). For the integrative use of all these information sources under the framework of research processes as illustrated in Figure 1, it is believed that a comprehensive resource of relevant information about research and development in the area of sensor-based systems for buildings can be retrieved and reviewed.

Literature Review

Literature review is one key research task at the first stage of research and development as illustrated in Figure 1. To further develop the Sense Diary system, the literature review into *sensor-based systems for buildings* has been being conducted in the Intelligent Buildings Research Group at the University of Reading. There are three focuses in the literature and products review, including a review into academic research based on primary information resource and database in engineering and management, a review into industrial and/or commercial applications based on the practice of industrial leaders, and a review into relevant products such as sensors based on the technical information from industrial leaders. Therefore, the literature review is the first focus in the whole review process. Actually, it has been noticed that some industrial and/or commercial products and/or applications have been developed based on academic research into sensor-based systems for buildings. In this regard, the literature review will has its limitation that only focuses on relevant academic research and development.

For a comprehensive literature review, two main kinds of academic literature have been targeted and pursued, including periodicals and books. The reason for this selection is that periodicals can

normally provide the most recent information about the review target; while books can give comprehensive information about relevant issues. For example, below is a literature review about sensor-based systems for buildings based on this review strategy.

According to recent literatures such as the book edited by Gassmann and Meixner (2001), the main areas of *sensor-based systems for buildings* cover with the following five streams of research and development, which include

- energy and heating ventilation & air conditioning (HVAC) such as self-commissioned heating control system using Artificial Neural Networks (ANN), air-conditioning control, air quality measurement and management, sensor-based management of energy and thermal comfort, sensors in HVAC systems for metering and energy cost allocation, and pressure sensors in the HVAC systems, etc.;
- information and transportation such as wireless and M-Bus enabled metering devices, field-bus systems, wireless in-building networks, sensor systems in modern high-rise elevators, and sensing chair and floor using distributed contact sensors, etc.;
- safety and security such as life safety and security systems, biometric authentication for access control, smart cameras for intelligent buildings, and load sensing for improved site safety, etc.;
- maintenance and facilities management such as maintenance management in industrial installations, and worldwide facility management, etc. and
- system technologies such as sensor systems in intelligent buildings, and system technologies for private homes, etc.

This book provides a comprehensive information collection about sensor-based systems developed for buildings with literatures from all over the world. The summary to the five main streams of applications has actually revealed the most successful applications and active areas of research and development for sensor-based systems for buildings. From this point of view, the literature review has been conducted following the five streams. It has been identified by reviewing this book that modern sensor-based systems based on structured Wireless Sensor Network (WSN) have been applied in facilities management for the energy supply system, the HVAC system, and the safety and security system in buildings. In this regard, the proposed research into a Sense Diary system, which aims to set up an occupancy feedback system to be used at work or residential places to register various degrees of satisfaction/dissatisfaction with commonly design environmental factors, is within the main areas in the research and development of sensor-based systems for buildings, and the unique feature of the proposed Sense Diary system indicates that it is a novel device for facilities management with regard to the energy efficiency of buildings and the well-being of occupants.

In addition to the review based on the book of *Sensor-based Systems for Buildings* (Gassmann and Meixner, 2001), it is necessary to further review recent publications after 2001 when the book was edited and published. By using the research framework (see Figure 1), some relevant key literatures have been identified in regard to the creation of a Sense Diary system device. For example, it has been retrieved that Davidsson and Boman (2000) present a multi-agent system for controlling intelligent buildings. In a de-regulated market the distribution utilities will compete with benefit for the customer in addition to the delivery of energy. They describe a system consisting of a collection of software agents that monitor and control an office building. It uses the existing power lines for the communication between the agents and the electrical devices of the building, such as sensors and actuators for lights, heating, and ventilation. The objectives are both energy saving and increasing customer satisfaction through value added services. Results of qualitative simulations and quantitative analysis based on thermodynamically modelling of an office building and its staff using four different approaches for controlling the building indicates that significant energy savings, up to 40 per cent, can be achieved by using the agent-based approach. The evaluation also shows that customer satisfaction can be increased in most situations. In fact, this approach makes it possible to control the trade-off between energy saving and customer satisfaction (and actually increase both in comparison with current approaches).

For an extensive literature view, the process has to be continued in terms of new research and development in the area of sensor-based systems for buildings. And the process of the extensive literature review will continue by using the same research framework throughout the whole process of this research project. As technologies are fast developing, it can be therefore expected that more literatures will be reviewed in a final research report.

Products Review

Literature review has indicated that the research and development of a Sense Diary system for buildings is a creative and innovative practice. However, this practice need to be deployed based on current level of relevant technologies. In this regard, a products review is conducted, which aims to find out some relevant industrial systems that can be used for reference. According to current review, the following products have been identified as relevant solutions for the proposed Sense Diary device and its application system

Wireless Sensor Network

A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations (Römer and Mattern, 2004; Haenselmann, 2006). The development of WSM was originally motivated by military applications such as battlefield surveillance; however, the WSN is now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, and traffic control (Römer and Mattern, 2004; Hadim and Mohamed, 2006). The WSN can bring a broad range of diverse applications from house to commercial buildings, from simple system to complex system. The advantage of WSN set up based on wireless network other than traditional wired network can just fulfil the requirements of occupants who want much interior space from the building services systems.

To review current applications of WSN in the built environment, two commercial systems have been identified as good applications. One example is for commercial buildings and the other one is for residential buildings. For the WSN applied in commercial buildings as well as households, the example is GAMMA Building Management System from Siemens (2006a); meanwhile, for the WSN applied in residential buildings, the example is the CyberEye system from Sungji (2006).

Commercial Initiatives

As the proposed Sense Diary is to be integrated with a local WSN either within a residential building or within an office building, another part of products review goes to control devices; and six set of commercial systems have been reviewed, including

- The Secom building services control station (Secom, 2006), which is a *Building Services Panel* that tenants can use to control the turning on and turning off lighting and air conditioning according to pre-defined time zones.
- The Ambi-Rad SmartCom Control Unit (Ambirad, 2006), which is designed for warm air heater units and radiant systems and has been designed to consolidate the function of all previous control panels into one unit.
- The Echelon NES system (Echelon, 2006), which is a state-of-the-art, future-proof smart metering system that brings new features and benefits to every aspect of ones utility's operations - from metering and customer services to distribution operations and value-added business.
- The TAC Satchwell MicroNet (TAC, 2006), which is a modular building management system that is easy to specify, operate, and tailor. It is suitable for small to medium scale operations and is sold through a locally accredited partner network.

- The Microsoft Home (Lai, 2006; Microsoft, 2006), which simulates a domestic environment including a front door, entry/foyer, kitchen, family room, dining room, entertainment room and bedroom. The Microsoft's technology-laden home of the future aims to feature smart appliances connected by Web services and controlled by tablet PCs or cell phones.
- The Siemens Smart House (Siemens, 2006b), which is a range of options that enhance the functionality of any home and are easy to use. Once some basic *Standard Fit*, including pre-wired cables for lighting, heating, blinds, surround sound, audio, video, data, voice and living lighting, is installed, then home owners can really make their homes 'Smart' and evolve it as they may change the way of living, and it is also believed that the choice is endless. There are three options below for home owners to choose and match in regard to the level of functionality they require, and the three Siemens Smart Homes options are
    - The *Silver SMART Home Technology* package includes all the preliminary systems detailed in the *Standard Fit* package,
    - The *Gold SMART Home Technology* package includes *Standard Fit* preliminary cabling, plus all the features in the Silver package.
    - The *Platinum SMART Home Technology* package includes *Standard Fit* preliminary cabling, plus all the features listed in both the Silver package plus Gold package upgrades**.**

As the proposed Sense Diary system aims to develop a new control panel for intelligent buildings control in regard to real-time occupants' opinions, products review has mostly gone to devices and relevant technical platforms that all current systems adopted. And it has been identified that mobile phone and PDA are currently popular intermediaries applied in buildings management systems (Jung, 2006; Microsoft, 2006; Siemens, 2006b); in addition, touch screen devices are also popularly used in some buildings (Jung, 2006). For example, mobile phones are used as a controller in Siemens Smart Home (Siemens, 2006b), and PDA is also used in buildings control (T-Com, 2006). All these information indicates that the intermediary of the proposed Sense Diary system needs to be chosen from these devices or to be embedded into all kinds of these devices.

Research and Development

Strategy

According to the review of literature and products information in regard to sensor-based systems for buildings and the proposed research into a Sense Diary system, it has been noticed that there are many building management devices and systems in the world, and the trend of R&D can be identified as following:

- Multi-functional devices and systems based on WSN,
- Portable devices by with integrative function,
- Based on international standards,
- Easy use and minimum operation, and
- Reliable and energy-efficient.

Although there are some relevant devices using desktop, laptop, PDA and touch screen, the propose Sense Diary system is new and the idea is useful with regard to improving energy efficiency and fulfilling the requirements of well-being during the buildings services periods.

A Sense Diary System

The research into "Embedded Sensor Technology and Occupant Behaviour" aims to help building professionals to further understand building occupancy or use patterns during a period of occupancy time. This study will explore relevant issues related to the Sense Diary System, which is expected to aid managing energy use and monitoring building performance besides assessing occupants' well-being requirements in regard to real-time performance of building services systems and building

façade system. In particular, this study aims to identify the occupancy behaviour patterns associated with building use so as to find out a possible relationship among these variables, their carriers and energy use. As a result, a Sense Diary as a prototype intelligent sensor-based device to monitor these variables is introduced, and is to be developed and tested in collaboration with industrial leaders such as Siemens and Echelon, who promote interaction between UK science, engineering and industry.

To facilitate the research going further, the definitions of Sense Diary and its applied system are proposed first based on the idea originally put forward by Professor Derek J. Clements-Croome in 1980s (Clements-Croome, 2004). The Sense Diary is a user feedback panel which can be used by building occupants for inputting their satisfactory opinions upon well-being requirements based on indoor environmental status indication and their physical feeling. The Sense Diary in the format of software can be programmed into different devices such as PDA, laptop, desktop PC and even mobile phone and TV. The Sense Diary within the environment of Ethernet and/or wireless network of the building can exchange data with wired network server and/or wireless network server; various sensor data parameters such as temperature, air quality, light and sound, etc. can be received by the Sense Diary, and Sense Diary can transmit occupants' feedbacks to remote control centre for building services systems management or facilities management. The architecture of the Sense Diary System is illustrated in Figure 2.

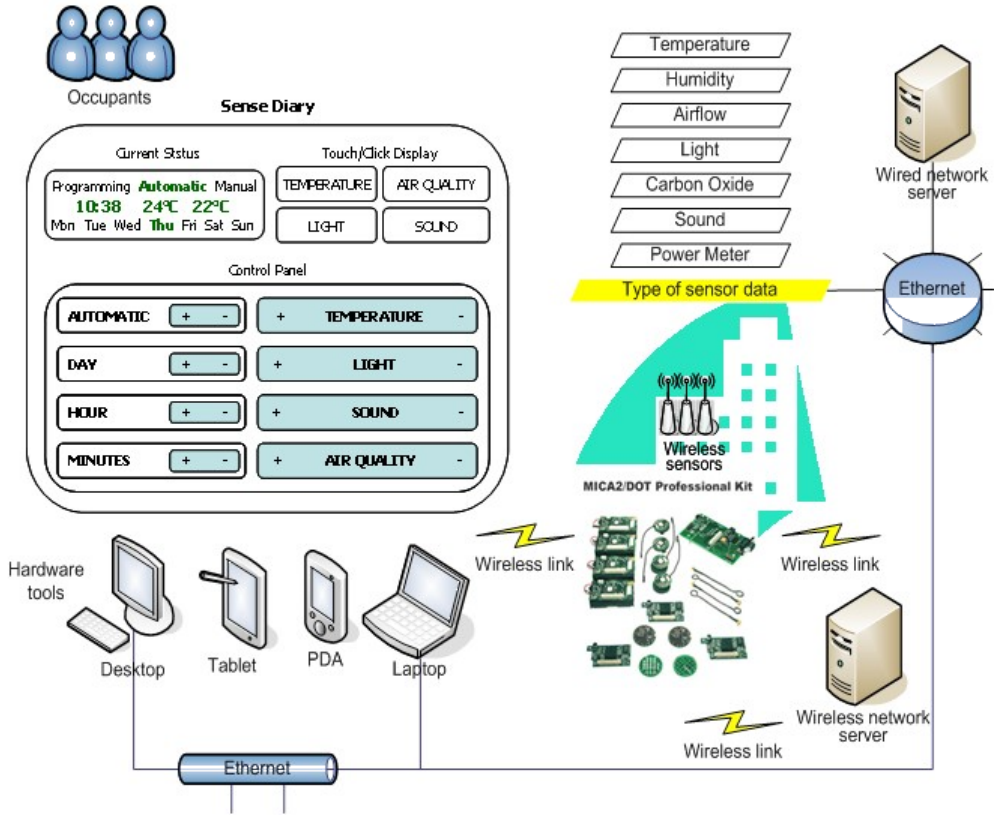

Figure 2: The Sense Diary System (Clements-Croome, 2004).

Conclusion

This paper introduces an on-going research into Sense Diary System for intelligent real-time control to residential and non-official buildings in regard to energy-saving and well-being. A system diagram about the proposed device and its related system has been described, which is based on a comprehensive review into current information from both academic and professional areas. Further

research will focus on the collection and analysis of experts' opinions in terms of the design of the proposed devise and its integration with diverse buildings management systems; furthermore, a demonstration system is expected to be developed at the end of this research.

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